WRITING POSITION DATA EX SITU USING AN ACTUATOR RETRACTABLE BY A RETRACTABLE SUPPORT ELEMENT

By

Brent Melvin Weichelt

Lon Richard Buske

Mark August Toffle

WRITING POSITION DATA EX SITU USING AN ACTUATOR RETRACTABLE BY A RETRACTABLE SUPPORT ELEMENT

Related Applications

This application claims priority of United States provisional application Serial Number 60/295,275 filed 1 June 2001.

Field of the Invention

This application relates generally to data storage devices and more particularly to recording position data onto discs thereof.

Background of the Invention

Disc drives are data storage devices that store digital data in magnetic form on a rotating disc. Modern disc drives comprise one or more rigid information storage discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers mounted to a radial actuator for movement of the heads relative to the discs. During a data write operation sequential data is written onto the disc track, and during a read operation the head senses the data previously written onto the disc track and transfers the information to an external environment. Important to both of these operations is the accurate and efficient positioning of the head relative to the center of the desired track on the disc. Head positioning within a desired track is dependent on head-positioning servo patterns, i.e., a pattern of data bits recorded on the disc surface and used to maintain optimum track spacing and sector timing. Servo patterns or information can be located between the data

sectors on each track of a disc ("embedded servo"), or on only one surface of one of the discs within the disc drive ("dedicated servo"). Regardless of whether a manufacturer uses "embedded" or "dedicated" servos, the servo patterns are typically recorded on a target disc during the manufacturing process of the disc drive.

Recent efforts within the disc drive industry have focused on developing cost-effective disc drives capable of storing more data onto existing or smaller-sized discs. One potential way of increasing data storage on a disc surface is to increase the recording density of the magnetizable medium by increasing the track density (i.e., the number of tracks per inch). Increased track density requires more closely-spaced, narrow tracks and therefore enhanced accuracy in the recording of servo-patterns onto the target disc surface. This increased accuracy requires that servo-track recording be accomplished within the increased tolerances, while remaining cost effective.

Servo patterns are typically recorded on the magnetizable medium of a target disc by a servo-track writer ("STW") assembly during the manufacture of the disc drive. One conventional STW assembly records servo pattern on the discs following assembly of the disc drive. In this embodiment, the STW assembly attaches directly to a disc drive having a disc pack where the mounted discs on the disc pack have not been pre-recorded with servo pattern. The STW does not use any heads of its own to write servo information onto the data surfaces, but uses the drive's own read/write heads to record the requisite servo pattern to mounted discs.

In light of the explosive trend toward higher track densities in recent years, some exceeding 100,000 tracks per inch, this conventional method has become excessively time consuming. As the trend continues, it will apparently be necessary for every disc drive manufacturer to obtain and operate much larger numbers of STW's to maintain comparable numbers of disc drives. One strategy to mitigate this need is to utilize multi-disc "ex situ" STW's, which are are capable of recording servo patterns to multiple discs mounted in a stack. After writing some of the position information using (dedicated) servo recording heads, sequentially or simultaneously, the discs are then removed and loaded into disc drives for use. The disc drives write additional position information.

Several problems have made the use of ex situ writers commercially unfeasible. For example, it is not feasible to unload their servowriter heads onto a textured landing zone after servowriting. Applicant has limited knowledge of an ex situ multi-disc STW with an unload ramp structure that can be positioned near the outer diameter of a stack of horizontal discs. This STW, developed by Phase Metrics of Fremont, California, uses a sliding plate to position the ramp structure and a rotary actuator simultaneously. Unfortunately, the exact composition and operation of this ramp structure might not be public and is not known to Applicant. From extensive experience in this field, however, Applicant does know that positioning a ramp structure affixed to a massive plate that also supports a rotary actuator for accessing a disc stack is unduly expensive and/or imprecise.

To support cost effective ex situ STW operation in high volume, what is needed is a workable system for unloading an actuator that can extend between discs in a stack for load/unload, and retract for easy removal of the disc stack. The present invention provides a solution to this and other problems, and offers other advantages over the prior art.

Summary of the Invention

Servo Track Writers implementing the present invention use a support element that can extend between discs in the stack, and can also retract, permitting a high level of variation in the stack's positioning. In a preferred embodiment, the support element has an engagement surface that is wide enough to permit the element to support the actuator throughout the element's range of motion. For precise and cost effective operation, the element may also use a rotary actuator for a rigidly limited range of motion, preferably with an axis of rotation substantially parallel to those of the disc stack and the actuator.

Because the support structures are retractable, they can use low angles of approach (like those of hyperbolic-shaped cams) without losing access to the outermost portions of the discs. Disc drive ramps typically use an approach angle of 30 to 45 degrees relative to the disc surface, too steep to permit a low-flying STW head from loading without colliding with the disc surface. In a preferred method of the present invention, the support structure

is moved out of the servowriter actuator's path while position data is written to the outermost portions of the data surface.

Additional features and benefits will become apparent upon reviewing the following figures and their accompanying detailed description.

Brief Description of the Drawings

Fig. 1 shows a data storage device containing position data written by means of the present invention.

Fig. 2 shows a flowchart of a method of the present invention

Figs. 3 - 5 shows the relative positions of basic components of a Servo Track Writer (STW) configured to implement the present invention, in unloaded, transitional, and loaded positions respectively.

Fig. 6 shows a much more detailed (top) view of the STW of **Figs. 3-5**.

Fig. 7 shows a detailed perspective view of the STW of **Figs. 3-5.**

Fig. 8 shows a detailed magnified view of the stack of discs, the actuator and the support structure in a loaded position.

Detailed Description

Although the examples below show more than enough detail to allow those skilled in the art to practice the present invention, subject matter regarded as the invention is broader than any single example below. The scope of the present invention is distinctly defined, however, in the claims at the end of this document.

Numerous aspects of data storage device technology that are not a part of the present invention (or are well known in the art) are omitted for brevity, avoiding needless distractions from the essence of the present invention. For example, this document does not include much detail about how to use "embedded" servo reference marks to position a disc drive's transducers. Neither does it include specific methods for handling pre-written

discs or installing them into a disc drive with minimal distortion. Specific materials for constructing components described herein are likewise omitted, typically being a simple matter of design choice.

Definitions and clarifications of certain terms are provided in conjunction with the descriptions below, all consistent with common usage in the art but some described with greater specificity. For example, "position data" refers herein to any data that pertains to a physical location on a media surface such as a track number, a defect table entry, or a servo burst.

Turning now to **Fig. 1,** there is shown a data storage device **100** constructed in accordance with a preferred embodiment of the present invention. Device **100** is a disc drive including base **102** to which various components are mounted. Top cover **123** cooperates with base **102** conventionally to form a sealed chamber. The components include a spindle motor which rotates data storage discs **110** at several thousand revolutions per minute. Information is written to and read from tracks **112** on discs **110** through the use of an actuator assembly **161,** which rotates during a seek operation about a bearing shaft assembly **130** positioned adjacent discs **110**. Actuator assembly **161** includes a plurality of actuator arms which extend above and below each disc **110,** with one or more flexures extending from each of the actuator arms. Mounted at the distal end of each of the flexures is a transducer head **134** which includes an air-bearing slider enabling transducer head **134** to fly in close proximity above the corresponding surface of associated disc **110**.

Servo and user data travels through transducer head **134** and flex cable **180** to control circuitry on controller board **106**. Flex cable **180** maintains an electrical connection by flexing as transducer heads **134** traverse tracks **112** along their respective radial paths **138**. By "radial," it is meant that path **138** is substantially aligned with a radius of the disc(s) **110,** although their directions may be offset from a perfectly radial direction by up to about 20 degrees due to head skew, as is understood in the art.

During a seek operation, the overall track position of transducer heads **134** is controlled through the use of a voice coil motor (VCM), which typically includes a coil **122** fixedly attached to actuator assembly **161,** as well as one or more permanent magnets **120**

which establish a magnetic field in which coil **122** is immersed. The controlled application of current to coil **122** causes magnetic interaction between permanent magnets **120** and coil **122** so that coil **122** moves. As coil **122** moves, actuator assembly **161** pivots about bearing shaft assembly **130** and transducer heads **134** are caused to move across the surfaces of discs **161** between the inner diameter and outer diameter of the disc(s) **161**. Fine control of the position of head **134** is optionally made with a microactuator (not shown) that operates between the head **134** and the actuator arm.

Fig. 2 shows a method **200** of the present invention comprising steps **205** through **265**. Discs are assembled coaxially (alternated with spacers) into a stack **210**. A support element is extended between the discs so that the servowriter head can load **215.** A servowriter head (also between discs) writes servo marks onto a data surface **220**. (Typically many millions of such servo marks are thus written.) Many suitable techniques for writing servo marks are known in the art. The actuator supporting the head then moves out from between the discs, sliding onto an engagement surface of a support element also extending between the discs **225**. After the actuator is moved out from between discs, the support element starts to move out also **235**. Each continues moving until it reaches an extreme position in its (limited) range of motion **240**. The discs are removed (axially) from the stack **250,** and at least one of them is installed into a disc drive **255** (such as **100,** which shows two pre-written discs **110**). The marks are "pre-written," as are the discs, because the writing precedes installation into the disc drive **100**. Finally the pre-written servo marks are used to position the disc drive's transducer(s) as additional position data is written onto the data surface. This may include self-written servo tracks, "Zero Acceleration Path" factors or similar position correction factors, defect tables, and the like.

Figs. 3 - 5 show basic components of a servo track writer for implementing the present invention. Prior to installation in a disc drive **100,** a stack of discs **110** having a nominal radius **119** is positioned for rotation about an axis **113**. The discs have a conventional textured landing zone **117** and a useable data surface having a width **118** that is very flat and smooth.

Near the outer circumference of the discs **110** is a servowriter actuator **320** having a load tang **325** on each arm thereof, each load tang **325** resting on an a respective engagement surface **416** of a comb-like support structure **310**. Support structure **310** is rotatable about its axis **313,** and actuator **320** is rotatable about its axis **323**. As the discs begin to rotate (counterclockwise as shown in **Fig. 4**), support structure **310** likewise rotates counterclockwise until it extends between (and on both ends of) the stack of discs **110**. This can occur because the actuator **320** slides along each engagement surface **416**. The discs **110** continue to accelerate, meanwhile, to a load velocity so that the actuator can rotate counterclockwise to load the servowriter heads onto (i.e. flying adjacent) the disc **110**. Once the heads are loaded, the support structure moves to a partially retracted position about 5 or 10 degrees clockwise from that shown in **Fig. 5**) and the discs are decelerated by at least 5% for servo writing operations.

The depicted embodiment of **Figs. 3 - 5** have several advantageous features. Note that the support element **310** is elongated enough to extend between the discs by a distance greater than R/10, where R is the nominal disc radius **119**. This elongation permits the engagement surface **416** to include a sloped portion **517** that is less than about 25 degrees, and more preferably about 7 degrees, relative to the disc surface. Ordinarily, approach angles in this range would not be feasible because of the significant portion of the disc rendered inaccessible. Gradual approach angles are desirable, however, because they prevent low flying heads from diving into the disc upon loading. (Servowriter heads that fly at 0.7 to 1.0 microinch or less are highly desirable, for example with magnetic discs, because they make it possible to use a medium having a higher coercivity, which in turn permits higher data density.) Because the present invention makes use of a retractable support element **310**, a gradual approach is possible without losing access to the outermost portions of the disc **110**.

Fig. 6 shows a much more detailed view of a servo writer **600** implementing the present invention. The writer **600** has several components supported by a substantially immobile and horizontally positioned platform **612**. The platform **612** is substantially resistant to movements from impact type collisions, preferably implemented as a granite

slab or comparably heavy material weighing tens or hundreds of pounds. A sliding assembly **602** is connected to the platform **612** via a slide mechanism **614** for lateral movement (as indicated by arrow **616)** over the platform **612** between a servo recording position **618** and a component access position **619,** as is discussed in greater detail below. The spindle motor hub assembly **606** and vacuum chuck **608** are directly and non-moveably secured to the platform **612**.

In the preferred embodiment as shown, the sliding assembly **602** and the spindle hub assembly **606** of the STW **600** are both upright. Thus, the plurality of discs **110** secured to the spindle hub assembly **606** are vertically positioned relative to the platform **612**. It is believed that the substantially vertical orientation of the discs **110** improves the accuracy of the servo pattern that is written to each of the discs by the STW **600,** as explained in greater detail below. Similarly, the sliding assembly **602** includes a rotary actuator **320** (see **Fig. 3**) having a plurality of actuator arms **824** (see **Fig. 8**) that are also arranged for movement in substantially vertical planes relative to the platform **612**. Each actuator arm **824** includes one or more flexures **826** connecting a distal end of the actuator arm to a corresponding one of the servo-writing heads **804**. The vertical orientation of the actuator arms **824** also increases the accuracy of the servo writing process as described below.

Fig. 6 illustrates the STW **600** in the load/unload position **619** where the sliding assembly **602** has been moved away from the spindle hub assembly **606** via the slide mechanism **614**. In this position, a stack of discs **110** may be loaded onto spindle hub assembly **606** to start the servo writing process. The spindle hub assembly **606** optionally includes a detachable spindle hub **828** (of **Fig. 8**) so that the hub **828** and the stack of discs **110** may readily be detached from a spindle motor (not shown in **Fig. 8**) to ease the process of loading and unloading the discs **110** from the spindle hub **828**.

Once the discs **110** have been loaded on the spindle hub assembly **606** with a predetermined gap between adjacent discs, the discs **110** are secured to the spindle hub assembly **606** by means of a clamp ring **730**. The sliding assembly **602** is then preferably moved laterally along the platform **612** (in the direction of arrow **616**) toward the spindle hub assembly **606**. While the flexures **826** on each of the actuator arms **824** tend to bias

their corresponding heads **804** as is well known in the art, a support element **310** is used to maintain proper separation between the heads **804** so that the sliding assembly **602** and the disc stack on the spindle hub assembly **606** may merge without unintentional contact between the heads **804** and the discs **110**. The support element **310** preferably moves together with the sliding assembly **602** as shown in **Fig. 8** and acts to separate the heads **804** against the bias force of the flexures **826**. Once the sliding assembly **602** is locked into the servo writing position **618** so that the heads **804** are positioned within the gaps between the adjacent discs **110**, the support element **310** is rotated away from the actuator **320** to allow the heads **804** to engage their respective discs as a result of the bias force provided by the flexures **826**. Of course, the heads **804** do not make physical contact with the data regions of their respective disc surfaces. Rather, the spindle hub assembly **606** is activated to spin the discs **110** at a predetermined rate prior to disengaging the support element **310**. As described above, the rotational motion of the discs **110** generates wind so that the heads **804** ride an air bearing in lieu of actually contacting the disc surface. This air bearing counters the bias force applied by the flexures **826** and protects the fragile magnetic coatings on the disc surfaces.

Once the support element **310** is removed so that the heads **804** are fully engaged with their respective discs **110**, servo writing signals are applied to the heads **804** to begin the process of recording the servo pattern. During the recording process, the actuator **320** is rotated about a horizontal axis by a motor and bearing assembly within the sliding assembly **602** so that the heads **804** move radially across the surface of their respective discs **110**. The position of the heads **804** is determined by the laser interferometer **610** which utilizes interferometric techniques to track movement of the heads along the disc radius, and the interferometer **610** sends position signals back to control the operation of the sliding assembly **602** and thus the radial position of the heads **804**.

Upon completion of the servo writing process, the actuator **320** is rotated back to position the heads **804** adjacent an outer circumference of the discs **110**, while the support element **310** is rotated into contact with the flexures **826** to disengage the heads **804** from the discs **110**. The sliding assembly **602** is then moved laterally away from the spindle hub

assembly **606** to the load/unload position **619** so that the discs **110** (complete with their newly written servo patterns) can be removed from the spindle hub assembly **606** and ultimately installed in the disc drive **100**.

Advantageously, the vertical orientation of the sliding assembly **602** prevents the force of gravity from pulling the heads **804** downward. This is important both during the loading and unloading of the heads **804** onto the discs **110** as well as during the servo writing process itself. For instance, while the support element **310** acts to separate the heads **804** prior to the loading process, it is noted that the support element **310** typically contacts the flexures **826** rather than the fragile heads **804** located at a distal end of the flexures **826**. Thus, with horizontally-oriented STWs, the force of gravity may tend to pull the heads **804** downward below the level of the individual support element arm or tine, thereby creating a danger of inadvertent contact between the hanging head **804** and the disc **110** prior to the disengagement of the support element **310** from the flexures **826**. This danger is avoided in the current invention since the force of gravity does not tend to pull the heads **804** in the direction of the discs. Additionally, during the servo writing process utilizing the present invention, the force of gravity does not tend to pull the heads **804** either toward or away from their respective disc surfaces as in the prior art. That is, in a horizontally-oriented STW, half of the heads are typically positioned adjacent a top surface of a disc, while the other half of the heads are positioned adjacent a bottom surface of a disc. For those heads positioned above their respective discs, the force of gravity on the flexure **826** and the head **804** is support elementined with the preload force generated by the flexure **826,** while for those heads positioned below their respective discs the force of gravity acts against the preload force. This dichotomy can create fluctuations in the preload force for the different heads within the STW which ultimately leads to discrepancies in the "fly height" of the head over the disc surface. While the preload force provided by the flexure is typically much greater than the weight of the flexure and head support elementined, even minor discrepancies in the fly height of the head during the servo writing process can lead to errors in the servo pattern.

In addition to the above-described benefits relating to the substantially vertical orientation of the sliding assembly **602** (i.e., the movement of the actuator arms **824**, the flexures **826** and the heads **804** in a vertical plane), the substantially vertical orientation of the discs **110** on the spindle hub assembly **606** also provides benefits over prior art horizontally-oriented STWs. Specifically, while the discs **110** are formed from a relatively stiff material (such as aluminum), the discs are nonetheless subject to gravity-induced warping, particularly along the outer circumference of the discs. As described above, even miniscule amounts of disc warpage can lead to unacceptable servo-writing errors, particularly in light of the higher track densities utilized with the discs. However, by maintaining the discs **110** in a vertical orientation during the servo writing process, the force of gravity does not act to pull the disc surface from its nominal vertical plane. Thus, the vertical orientation of the STW **600** of the present invention (i.e., the substantially vertical orientation of both the sliding assembly **602** and the discs **110**) provides a number of benefits over prior art horizontally-oriented STWs.

A perspective view of the sliding assembly **602** in relation to the STW of **Fig. 6** is shown in **Fig. 7**. The sliding assembly **602** includes an sliding block **762** housing a rotational air bearing and a translational air bearing (not labeled), an actuator **320** that includes an E-block, several actuator arms **240** carrying recording heads **140** thereon, a DC torque, brushless motor **768** or like motor for actuating the rotational air bearing **152**, a sliding mechanism **754** for translational movement of the sliding block **762**, and a laser transducer assembly for coordinating the motor's movement with the servo recording head's position.

The slide mechanism **754** is used, in coordination with the translational air bearing, to laterally move the sliding assembly **602** over the platform **612** toward and away from the spindle motor hub assembly **606**. The slide mechanism **754** attaches to a lower edge of a side face of the sliding assembly **602**, and preferably to a lower edge of the side face adjacent the vacuum chuck. The slide mechanism **754** includes a pneumatically sliding cylinder attached to the platform **612** by a flexure or bracket. A pair of stops **782** extend along the lower edge of the side face of the sliding block **762** on opposite sides of the

actuator block attached sliding mechanism. Each stop **782** extends beyond the front face and back face **786** of the sliding block **762**. A pair of catch block **787** is positioned on the platform **612** on opposite sides of the sliding block **762** to contact each stop when the sliding mechanism **754** laterally moves the sliding assembly **602** to the servo recording position on the platform.

Fig. 8 shows a magnified view of the stack of discs **110**, the actuator **320**, and the support structure **310** positioned to permit the servo-writing heads **804** to operate. Notice that the clamshell-shaped air dam **889** protrudes between the discs and that the support structure **310** does not, in this position.

Alternatively characterized, a first embodiment of the present invention is an apparatus (such as **100, 600**) for writing position data onto a first data storage disc (such as **110**). A spindle assembly (such as **606**) is configured to support first and second discs (such as **110**) rotatably in a stack. An actuator (such as **320**) is configured to support a servowriter head (such as **804**) between the discs to write several servo marks onto a data surface of the first disc (such as in step **220**). A support element (such as **310**) is configured to allow sliding contact with the actuator to unload the servowriter head from the data surface (such as contain tracks **112**). The embodiment further includes means for retracting the actuator and the support element from between the first and second discs. Such means may be an engagement surface of a cam structure configured to support the actuator while the cam structure rotates out from between the first and second discs.

In a second embodiment, the stack has a substantially horizontal axis of rotation. The support element optionally had a substantially parallel axis of rotation, although it is conceivable that the support element may be linearly actuated. The support element may also be a rotary actuator having an axis of rotation skewed to that of the disc stack, such as that of U.S. Patent 5,283,705 ("Head Retraction Mechanism for a Magnetic Disk Drive") issued 1 February 1994 to Masanori Iwabuchi.

In a third embodiment, the actuator is rigidly but rotatably supported by a first rigid body (such as **602**). The spindle assembly is likewise rigidly but rotatably supported (by a

second rigid body such as **612**). Automated means such as an air bearing/vacuum chuck mechanism are provided for coupling the first and second rigid bodies together temporarily during a servowriting operation.

A fourth embodiment is a method for writing position data. Several discs, preferably at least 8, are assembled coaxially in a stack (such as in step **210**). A servowriter head supported by an actuator writes several servo marks onto the data surface (such as in step **220**). The actuator is moved out from between the discs by sliding (an arm of) the actuator onto an engagement surface of a support element (such as **310**) that extends between the first and second discs. The support element is moved out from between the discs as the actuator slides on the engagement surface (such as in steps **235** and **240**). After these movements, the discs can easily be removed from the stack (such as in step **250**).

All of the structures and methods described above will be understood to one of ordinary skill in the art, and would enable the practice of the present invention without undue experimentation. It is to be understood that even though numerous characteristics and advantages of various embodiments of the present invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this disclosure is illustrative only. Changes may be made in the details, especially in matters of structure and arrangement of parts within the principles of the present invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the position data written can take the form of a pattern of holes in the magnetic media, rather than being written as a pattern of magnetized portions of the disc, without departing from the scope and spirit of the present invention. In addition, although the preferred embodiments described herein are largely directed to magnetic disc drives, it will be appreciated by those skilled in the art that many teachings of the present invention can be applied to optical and magneto-optical disc drives without departing from the scope and spirit of the present invention.